HORSFORD

SERVICE-PIPES FOR WATER

SERVICE-PIPES FOR WATER:

AN

INVESTIGATION

MADE AT THE SUGGESTION OF

THE BOARD OF CONSULTING PHYSICIANS OF BOSTON,

BY

E. N. HORSFORD,

RUMFORD PROFESSOR IN THE UNIVERSITY AT CAMBRIDGE.

From the Proceedings of the American Academy of Arts and Sciences.

CAMBRIDGE:
METCALF AND COMPANY,
PRINTERS TO THE UNIVERSITY.
1849.

SERVICE-PIPES FOR WATER.

Materials for the transmission of water, to be used as a beverage in any form, should be strong and durable, admit of ready repair and replacement, be sufficiently cheap to permit general use, and, above all, should impart no deleterious property to the waters served through them.

The safety of employing water supplied through wooden aqueducts, and the certainty of their rapid decay, are too well known to require more particular mention.

Pipes of iron, tin, of tinned iron, tinned copper, tinned lead, glass, and gutta percha, are of comparatively recent introduction. They are believed, so far as experience has shown, to impart few or no deleterious properties to water as a beverage, though all of them are wanting in some of the essential attributes just mentioned.

As pipes of lead have been long in use, and possess in an eminent degree most of the properties required for aqueduct service, and as the following research has been more especially directed to ascertain the true value of leaden pipes for the distribution of water, a brief historical sketch of the opinions that have been entertained with regard to the safety of employing them may not be without interest.

The period of the first employment of lead for transmitting water is unknown; but the circumstance that it was condemned by Vitruvius, a Roman architect believed to have lived about nineteen hundred years ago, is evidence of its having at that time been long enough in use to furnish experience as the basis of its rejection as a material for

aqueducts.* Galen, a physician of Amsterdam, who wrote in the seventeenth century, coincided with Vitruvius. Both had observed the formation of white lead in water-pipes, and attributed to it the illness which was known to affect those who drank certain waters served through leaden pipes. Notwithstanding these strongly expressed opinions and occasional fatal consequences from drinking water containing lead in solution, public sentiment continued strongly in favor of this kind of pipes, and until about the commencement of the present century no experimental examination of the subject had been undertaken. Dr. Lamb of England, and later Guyton Morveau of France, devoted their attention for a time to this inquiry. Their opinions are evidence of what must attend the earlier labors in every field of investigation. The one believed that most, if not all, spring waters possess the property of acting upon lead to such an extent as to render their conveyance through leaden tubes unsafe, and this *because of the salts in solution;* — the other, that many natural waters scarcely act on lead at all, and *because of the salts in solution.* The former believed that rain or snow water (eminently pure) does not corrode lead; the latter, that distilled water, the purest of all waters, acts rapidly on it. Dr. Thompson of Glasgow subsequently gave some consideration to the subject, and came to the conclusion that, though Dr. Lamb's general proposition was true, the lead was not *dissolved*, but *suspended merely.*

Such was the doubt upon this point, — the insolubility of oxide of lead, — that a scientific association in Germany made it a prize problem. The honor of deciding the question was accredited to Brendecke, whose views were coincided in by his unsuccessful competitor, Siebold,† and also by Herberger, who prepared his oxide of lead in a different manner, and reported his results at a later period. They decided that *oxide of lead is insoluble* in water.

The imperfection of the investigation and the injustice of this award have since been established by the labors of Yorke,‡ and Bonsdorff,§

* Leaden pipes may be seen at this day among the ruins of the Coliseum, and leading to the baths and fountains of Herculaneum and Pompeii.

Kopp thinks lead as a metal was known to the Israelites. *Geschichte der Chemie.* It is certain that it was known and in use 400 years before the Christian era.

† *Phar. Cent. Blatt*, 1835, p. 831; *Buch. Rep.*, III., pp. 155–179.

‡ *Pogg. Ann.*, XXXIII., pp. 110–112.

§ *Phar. Cent. Blatt.*, 1836, p 520; *Buch. Rep.*, V., pp. 55–59.

who have found that aerated, distilled water, deprived of carbonic acid, oxidates metallic lead and dissolves the oxide in the proportion of from $\frac{1}{7000}$th to $\frac{1}{12000}$th. Even the acute Scheele had remarked the same fact in the last century. Philips denied the accuracy of the conclusions of both Yorke and Bonsdorff, and maintained, with Thompson, that the oxide of lead was not soluble, but was only in suspension. His view was supported by the fact, that filtration seemed to separate the lead from the water that originally contained it. In 1846 Yorke* reviewed the investigation of Philips, and showed that, in the process of filtration, the oxide of lead enters into combination with the woody fibre of the filtering paper. By filtering for some time through the same paper it became saturated, and the lead in solution passed without detention.

Christison, to whom we are indebted for a careful record of the principal conflicting opinions upon this subject, repeated and extended the experiments of Guyton Morveau, to ascertain the effect of solutions of certain salts in water. He came to the conclusion that arseniates, phosphates, sulphates, tartrates, and even chlorides, acetates, and nitrates, possess the power of protecting lead from the action of the water. Of the nature of this protecting power he acknowledges that he has no clear conception. He assured himself that it does not in all cases arise from the formation of an insoluble coat consisting of the acid of the employed salt united to the oxide of lead, by finding that the coat, which for the most part, in his experiments, consisted of carbonate of lead, readily dissolved in acetic acid. This author has suggested that leaden pipes, before being laid down for service, should be exposed a length of time to solutions of some of the salts, denominated *protecting*, since he had observed that leaden pipes, which poisoned certain waters when first served, after a time became coated, and passed the same waters without injury to the health of those who drank them.

The city of London has long been supplied with water distributed through lead, and though occasional excitements upon this subject have sprung up in Great Britain from individual cases of poisoning, the prevailing public sentiment is in favor of lead. Professor Graham states that in London lead only is used for service-pipes.

The exemption of Paris from illness derived from this cause is

* *Phil. Mag.*, XXVIII., pp. 17–20.

asserted by Tanquerel.* This is believed to be true of all the larger European towns whose inhabitants are supplied with water from public reservoirs. On the other hand, the inhabitants of Amsterdam were poisoned by drinking rain-water that had fallen on leaden roofs. Upon replacing the lead with tiles, the maladies ascribed to the former disappeared.

We find ourselves at the conclusion of the literature of the Old World upon this subject with these impressions : —

1st. That some natural waters may be served from leaden pipes without detriment to health.

2d. That others may not ; and

3d. That we have no method of determining beforehand whether a given water may or may not be transmitted safely through lead.

Professor Silliman, Jr., in his able report on the various waters submitted to him by the Water Commissioners, in 1845, has given the results of some experiments upon the action of several waters on lead, which conducted him to the general conclusions above expressed.† Among those who have taken strong ground against leaden service-pipes for the transmission of water may be mentioned Drs. Chilton and Lee of New York, and Drs. Dana and Hayes of Lowell.

The occasion of the following research was the request by the Board of Consulting Physicians of the city of Boston, in January of 1848, that a comparison of the action of Cochituate Lake, Jamaica Pond, and Croton and Schuylkill River waters upon lead should be instituted.

Cochituate water was about to be introduced into Boston for the supply of the city. Jamaica water has been employed in certain sections of the city of Boston since the year 1795, and for the last twenty years served through leaden pipes. Croton River water, since 1842, has been supplied through iron mains and leaden service-pipes to the citizens of New York, a city of 400,000 inhabitants. Schuylkill River water, since the year 1815, has been supplied through iron mains and leaden distribution-pipes to the inhabitants of Philadelphia, a city of 300,000 inhabitants.

The inquiry that early presented itself to the Board of Consulting

* Tanquerel *on Lead Diseases*, edited by Dana, App., p. 396.

† *Boston Water-Com. Report*, App., 1845.

Physicians was the following: — *Will there be greater liability to lead-disease from drinking Cochituate water served through iron mains and leaden pipes, than there is now from drinking Fairmount or Croton waters similarly served, or Jamaica water possibly less favorably served than Cochituate water will be?*

To answer this question, Croton, Fairmount, Jamaica, and Cochituate waters were provided with care, and the proposition made, that lead should be presented to them all under similar circumstances.

It was not proposed to introduce the absolute conditions of actual service in a series of laboratory experiments. It was conceived that, when in contact with lead, all the external circumstances being the same, the differences in the action upon lead would be a kind of exponent of the differences in constitution among the waters.

A sufficiently extended series of experiments, it was believed, would reveal all the expedients to be resorted to in order to the fulfilment of the required conditions, and would, if duly protracted, furnish replies to the various inquiries into which the main problem of the measure of safety or danger resolved itself.

Should the experiments result in showing that the several waters were alike in their action upon lead, then would the citizens of Boston, in drinking Cochituate water served from leaden pipes and iron mains, be as little liable to lead-disease as are the citizens of Philadelphia and New York who drink Schuylkill and Croton water similarly served, and that portion of the citizens of Boston who have for nearly a quarter of a century employed Jamaica water served through lead. Should Cochituate water be found to act less on lead than Jamaica water, all external circumstances being the same, then would the question be affirmatively and more satisfactorily decided; since these two waters occur in the same geological associations, are about equally pure, and the latter has been drank under less favorable circumstances than Cochituate will be, so far as the relations to lead are concerned. On the other hand, should the inequality in action of the waters be great, and that of the Cochituate uniformly most energetic, then would the question, so far as this mode of investigation could influence it, be decided in the negative.

The experimental result being favorable, the question of probable future illness to arise from drinking Cochituate water would be decided by an appeal to those physicians of New York, Philadelphia, and Boston, whose extensive practice and standing in the profession demand

confidence in their opinions; and by an appeal to public sentiment, where every day's experience among all classes, the less and the more careful, contributes to its formation.

Such experiments have been made with all the waters above mentioned, and at the same time, in many cases, parallel suites with Albany and Troy reservoir waters, Cambridge well-water, and distilled water, contemplating all the conditions that could be expected to occur.

They were conducted in an apartment where, with rare exceptions, no other laboratory labor was carried forward than that connected with this investigation, and in which the tests with hydrosulphuric acid were not made. Whatever influences from temperature or other causes operated upon any one of the waters operated equally upon each of the others. With the exception of Cochituate water, which possessed a yellowish-brown tint, the samples were colorless.

A determination of their general relations to each other was made.*

Albany Reservoir Water. — 500 cubic centimetres evaporated to dryness in a platinum capsule over a water-bath gave, of solid residue, 0.0924gr. Ignited, the above residue lost 0.0198gr.

Cambridge Well-water, that does not act on lead so as to produce known deleterious effects. — 500cc. evaporated to dryness over a water-bath gave, of solid residue, 0.3918gr.; of which 0.0990gr. were expelled by ignition, and of the non-volatile matters 0.0676gr. were insoluble in boiling water.

Cambridge Well-water, that, in an inch-and-a-quarter pipe several years in use dissolves a grain and a half of lead in thirty-six hours. — 500cc. evaporated to dryness over a water-bath gave, of solid residue, 0.1380gr.; of which 0.0540gr. were expelled by ignition.

Cochituate Lake Water. — I. 500cc. evaporated to dryness over a water-bath gave 0.0267gr. of solid residue; of which 0.0122gr. were expelled by ignition, and 0.0050gr. of the remainder insoluble in boiling water. — II. 500cc. over a water-bath gave a solid residue of 0.0267gr.

Croton River Water. — 500cc. evaporated to dryness over a water-bath gave, of solid residue, 0.2175gr.; of which 0.1496gr. were expelled by ignition.

Fairmount Water, Schuylkill River. — 500cc. evaporated to dry-

* Professor Silliman, Jr. has made a similar determination of the relations of the Croton, Cochituate, and Fairmount waters. *Water-Com. Report*, 1845.

ness over a water-bath gave, of solid residue, 0.3007gr.; of which 0.1032gr. were expelled by ignition, and of the non-volatile matters 0.0239gr. were insoluble in boiling water.

Jamaica Pond Water. — 500cc. evaporated to dryness over a water-bath gave, of solid residue, 0.0268gr.; of which 0.0115gr. were expelled by ignition, and of the non-volatile matters 0.0070gr. were insoluble in boiling water.

Troy Reservoir Water. — 500cc. evaporated to dryness over a water-bath gave, of solid residue, 0.0593gr.; of which 0.0181gr. were expelled by ignition, and of the non-volatile matters 0.0278gr. were insoluble in boiling water.

The above results may be expressed in tabular form as follows: —

TABLE I.

	Residue.	Loss upon being Ignited.	Inorganic Matter.	Insoluble after Ignition.
	gr.	gr.	gr.	gr.
Distilled water,	0.0000	0.0000	0.0000	0.0000
Albany "	0.0924	0.0198	0.0726	. . .
Cambridge "	0.3918	0.0990	0.2928	0.0676
Cambridge water that acts on lead,	0.1380	0.0540	0.0840	. . .
Cochituate water,	0.0267	0.0122	0.0145	0.0050
" "	0.0267	. . .	. . .	. . .
Croton "	0.2175	0.1496	0.0679	. . .
Fairmount "	0.3007	0.1032	0.1975	0.0239
Jamaica "	0.0268	0.0115	0.0153	0.0070
Troy "	0.0593	0.0181	0.0412	0.0278

The following tables of results will sufficiently explain themselves. They exhibit quantities of lead which, for practical purposes, have little more than relative value in the columns in which they occur.

The experiments were made with bars of lead cast in a common mould, of uniform diameter and length. The quantities of water were constant, or as nearly so as might be, in the same series of experiments. The bars were covered, in test-tubes of a given diameter, with fifteen cubic centimetres.

After exposure out of direct sunlight, except where otherwise stated, a length of time indicated in the column of days at the left, a suite of similar tubes was filled to the requisite depth with corresponding waters, and the bars transferred with the least delay.

The waters were then acidulated with acetic acid, received each a

drop of acetate of potassa, — which Fresenius has observed decomposes all lead salts not decomposed by hydrosulphuric acid, — and exposed to a stream of washed hydrosulphuric acid till the liquid became clear, if it had been at first discolored by the precipitate of lead.

If concentration occurred, it is so stated. The quantities were estimated by a method to be described farther on.

Table II.

Experiments with Lead to ascertain the Action of Water on Successive Days.

One bar resting on the bottom of each test tube. Waters replaced at the date of each result.

Days.	Cochituate.	Croton.	Fairmount.	Jamaica.
1	5.000	2.000	7.000	10.000
3	0.500	0.500	0.000	10.000
4	1.000	0.500	2.000	0.000
5	10.000	2.000	5.000	1.000
6	0.100	0.100	0.100	0.500
7	0.100	0.100	0.100	0.100
8	0.200	0.200	0.200	3.000
11	0.100	0.100	0.100	1.000
12	0.100	0.100	0.200	0.500
13	0.000	0.000	0.100	0.500

The first modification of the experiment was in the extent of surface of lead.

Table III.

Experiments with Two Bars of Lead.

In all other respects the conditions were the same as in the foregoing experiments.

Days.	Cochituate.	Croton.	Fairmount.	Jamaica.
1	5.000	5.000	1.000	10.000
3	3.000	2.000	1.000	2.000
4	0.500	0.500	1.000	0.000
5	0.100	0.100	0.100	0.100
6	0.100	0.100	0.100	0.010
7	0.100	0.100	0.010	0.200
8	0.100	0.100	0.010	3.000
11	0.100	0.100	0.100	1.000
12	0.100	0.200	0.100	5.000
13	0.100	0.200	0.200	5.000

Table IV.

Experiments with Three Bars.

Other conditions same as before.

Days.	Cochituate.	Croton.	Fairmount.	Jamaica.
1	1.000	0.500	0.500	10.000
3	10.000	2.000	1.000	4.000
4	5.000	0.500	3.000	40.000
5	0.000	0.500	1.000	15.000
6	1.000	0.200	0.100	10.000
7	0.500	0.100	0.100	8.000
8	0.100	0.100	0.100	4.000
11	0.100	0.200	0.200	2.000
12	0.100	0.100	0.100	5.000
13	0.100	0.200	0.100	3.000

From the foregoing experiments it was deducible, —

1st. That the action upon lead was most energetic during the first few days of exposure.

2d. That the differences between the action on one, two, and three bars, the volume of water remaining the same, being inconsiderable, the action could not be dependent upon the *surface* of lead exposed, but upon some other constant condition.

The observation, that, where the bar touched the containing tube, the action seemed most vigorous, suggested an explanation of the want of uniformity in results. It further suggested experiments with *suspended bars*, the results of which are detailed in the following table.

Table V.

Experiments with Bars suspended out of Contact with the containing Vessel.

Waters not exposed to sunlight. Average results of four series of experiments. One bar to each tube. No concentration.

Days.	Cochituate.	Croton.	Fairmount.	Jamaica.
1	15.500	1.500	0.280	80.000
2	0.012	0.012	0.012	2.750
3	0.012	0.001	0.000	0.027
4	0.000	0.000	0.000	0.000

These experiments and the foregoing seemed to show that, without contact of the solid metal with the containing vessel, the influence of

the 'constant condition' was so far enfeebled, after the first few days, as not to have its effects recognized by the ordinary reagents, without concentration, after a period of twenty-four hours' exposure. The following table of results confirms this deduction.

Table VI.

Experiments with Water several Weeks exposed to Light and the Warmth of the Apartment in which the Experiments were made, by which much of the contained Air had been expelled.

Bars suspended out of contact with the tube. Volume as in the preceding experiments.

Days.	Cochituate.	Croton.	Fairmount.	Jamaica.	Distilled Water.
1	1.000	0.500	0.000	0.050	25.000
3	0.050	0.010	0.000	2.000	15.000
5	0.010	0.000	0.000	0.050	15.000
7	0.000	0.000	0.000	0.000	15.000
9	0.000	0.000	0.000	0.000	15.000
12	0.000	0.000	0.000	0.000	15.000
17*	0.020	0.010	0.000	0.000	30.000
24*	0.050	0.000	0.000	0.000	0.500
39*	0.500	0.000	0.100	0.100	3.000

As the street mains are of iron, it was desirable to know if the contact of lead with iron could be more injurious to Cochituate than to Croton, Fairmount, or Jamaica water. Experiments were also made with Albany and Troy reservoir waters, and the Cambridge well-water first in the order of succession in Table I.

Table VII.

Experiments with Lead and Iron.

Iron uppermost. Lead solder. Volume of water the same as in previous experiments.

Days.	Distilled Water.	Albany.	Cambridge.	Cochituate.	Croton.	Fairmount.	Jamaica.	Troy.
3	8.000	1.000	2.000	1.000	1.000	10.000	10.000	25.000
7	10.000	0.010	0.010	0.010	0.010	0.010	0.500	0.000
9	2.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
11	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
20	0.000	0.100	0.000	0.100	0.000	0.000	0.100	0.000
30	1.000	0.400	0.500	0.800	0.500	0.500	0.500	0.100
48	0.100	0.005	0.100	0.010	0.050	0.000	0.010	Lost.

* Water concentrated to one fourth of its volume.

Discoloration of the bars of lead was least in this order: — Albany, Cambridge, Croton, Fairmount, Distilled Water, Jamaica, Cochituate. That is, Cochituate, apparently, most promptly and completely coats the lead.

Table VIII.

Experiments with Lead and Iron.

Lead uppermost. Lead solder. Volume of water same as in previous experiments.

Days.	Distilled Water.	Albany.	Cambridge.	Cochituate.	Croton.	Fairmount.	Jamaica.	Troy.
2	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500
3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
7	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
16	0.010	0.010	0.100	0.010	0.010	0.010	0.010	0.010
26	0.500	0.100	0.010	0.010	0.010	0.010	0.010	0.010
44	3.000	0.050	0.100	0.100	0.100	0.100	0.100	Lost.

Sections of each bar at first less coated near the iron. Larger measure of protoxide of iron in Cochituate and Croton waters than in the others, as indicated by ferrocyanide of potassium. Discoloration of the bars least in this order: — Fairmount, Distilled Water, Albany, Troy, Croton, Jamaica, Cochituate.

Table IX.

Experiments with Lead and Iron.

Soft solder. Volume and other conditions as in previous experiments.

Days.	Distilled Water.	Albany.	Cambridge.	Cochituate.	Croton.	Fairmount.	Jamaica.	Troy.
3	10.000	6.000	6.000	6.000	1.000	10.000	7.000	7.000
12	. .	1.000	Lost.	1.000	1.000	1.000	1.000	2.000
17	30.000	0.000	0.050	0.010	0.500	0.000	0.500	0.000

As the stopcocks will, many of them, be of brass, it was important to ascertain the influence of this connection.

Table X.

Experiments with Lead and Brass.

Surfaces of lead and brass nearly equal. Volume of water as before mentioned.

Days.	Distilled Water.	Albany.	Cambridge.	Cochituate.	Croton.	Fairmount.	Jamaica.	Troy.
1	5.000	2.000	0.500	0.800	25.000	0.100	1.000	5.000
3	8.000	2.000	1.500	1.500	2.000	1.500	1.500	8.000
7	20.000	0.800	10.000	10.000	2.000	1.500	20.000	7.000
33	10.000	0.100	7.000	0.200	0.100	0.100	4.000	7.000
37	20.000	0.800	10.000	2.000	10.000	1.000	8.000	5.000
38	12.000	—	—	0.800	0.800	—	0.400	—
39	2.000	—	—	0.800	0.300	—	0.400	—
40	1.250	—	—	0.400	0.600	—	0.800	—
41	1.500	—	—	—	0.250	—	0.800	—
43	2.000	—	—	1.200	0.500	—	0.800	—

As some stopcocks may be of copper, a suite of experiments was made to ascertain the effect of this union.

Table XI.

Experiments with Lead and Copper.

A bar of lead and copper nail three fourths of an inch long. Lead solder.

Days.	Distilled Water.	Cochituate.	Croton.	Fairmount.
1	5.000	0.500	0.500	0.100
3	1.500	8.000	0.150	0.500
7	20.000	2.500	1.000	1.000
14	25.000	7.000	1.000	1.000
39	10.000	1.000	1.000	1.000
40	1.500	1.000	1.000	0.250
44	1.200	0.500	0.500	1.500
45	2.000	0.200	0.300	2.000
46	5.000	0.800	0.800	3.000
47	3.000	0.050	0.020	1.500
49	2.300	0.010	0.800	2.000

The effect of the contact of lead with tin, all the external circumstances being the same, is exhibited in the following table.

Table XII.

Experiments with Lead and Tin.

A half-bar of each soldered without alloy. Volume of water as before mentioned.

Days.	Distilled Water.	Albany.	Cambridge.	Cochituate.	Croton.	Fairmount.	Jamaica.	Troy.
1	40.000	0.500	0.500	0.500	0.500	0.500	0.500	0.500
8	60.000	0.100	0.100	0.100	0.200	0.500	0.800	0.500
32	50.000	1.500	4.000	0.500	0.100	1.500	2.000	—
36	12 000	—	—	0.050	0.050	—	1.500	—
38	1.500	—	—	0.500	1.500	—	3.000	—
39	2.000	—	—	0.500	0.300	—	0.400	—
40	0.500	—	—	0.500	0.500	—	0.700	—
41	2.000	—	—	0.010	0.010	—	0.010	—
43	3.000	—	—	0.010	0.020	—	0.700	—

Variation in some of the properties of the Cochituate water might be expected to take place. First, *in the percentage of organic matter.* Second, *in temperature.* Third, *in percentage of salts.*

The effect of increasing the percentage of organic matter is exhibited in the following table.

Table XIII.

Experiments with Lead in graduated Solutions of Organic Matter (Tannin) in Cochituate Water.

Days.	Cochituate.	Cochituate and $\frac{1}{100}$ of Tannin.	Cochituate and $\frac{1}{1000}$ of Tannin.	Cochituate and $\frac{1}{10000}$ of Tannin.	Cochituate and $\frac{1}{100000}$ of Tannin.	Distilled Water.
3	1.000	0.800	0.400	0.600	0.600	5.000
5	0.000	20.000*	0.500	0.250	0.250	20.000
6	0.500	2.000	0.500	0.100	0.100	4.000
7	0.000	2.000	0.200	0.000	0.000	3.000
8	0.050	0.500	0.100	0.000	0.000	2.500
10	0.000	0.500	0.000	0.000	0.100	3.000
11	0.000	0.000	0.000	0.000	0.000	2.000
12	0.100	0.000	0.000	0.000	0.000	3.000
13	0.050	0.000	0.000	0.000	0.000	2.000

The bars of the third and fourth columns became more or less coated with a loose reddish-brown coat of organic matter and lead.

The influence of increased organic matter of this form (which is as

* A kind of fungous or flocculent mass fell with the lead, augmenting the volume of the precipitate.

nearly allied to the vegetable matters that might be expected to occur in lake water as could be readily found) was to lessen the action on lead. The organic matters of lake and river waters consist of living and deceased organisms, animal and vegetable, and of soluble substances derived from decaying vegetation. When exposed a sufficient length of time, these matters become thoroughly inorganic. The carbon becomes carbonic acid, and the hydrogen becomes water, by the consumption of oxygen in solution in the water.

My experiments have shown, that, if the quantity of organic matter, such as the extract of bark, be more than $\frac{1}{10000}$ of the weight of the water, precipitates of the organic matter in combination with oxide of lead, if any is in solution, will take place. This is one of the methods frequently resorted to for separating organic bodies from solutions.*

The effect of temperature was sought in a variety of ways.† The following experiments are recorded.

Table XIV.

Experiments with Bars previously coated, exposed to direct Sunlight from the 21st to the 26th of June.

Bars resting on the bottom of the tubes.

Days.	Cochituate.	Croton.	Jamaica.	Distilled Water.
1	0.100	0.200	3.000	3.000
2	0.250	1.500	2.000	2.000
3	0.100	0.400	2.000	1.000
4	0.050	1.000	1.500	2.000

The influence of extreme temperature and exposure to air and moisture, under the most favorable circumstances, was ascertained by transmitting steam mixed with air through a leaden pipe thirty-six feet long, coiled like a still-worm, and placed in cold water to produce condensation.

One hundred and ten cubic centimetres of the condensed water, after acidulation with acetic acid, were treated with a stream of hydro-

* This precipitate is visible in Croton service-pipes five years in use. It occurs in the Jamaica service-pipes in Boston, and, I have been informed, in those of Fairmount water in Philadelphia.

† Dr. Hayes has observed that elevation of temperature increases the quantity of lead dissolved in a given time. — *Report of Consulting Physicians*, 1848, p. 24.

sulphuric acid. The precipitate was collected on a filter, previously dried at 100° C., and gave 0.0225gr. of sulphide of lead, equal to 0.0196gr. of lead, which is equivalent to 0.8095gr. of lead in a gallon.

Whatever influence might result from such changes, it must be remembered that pipes under ground will preserve a tolerably even temperature; and be the effect of increased heat what it may, it has been *more* energetic in Philadelphia than it ever can be in Boston.

The effect of increasing the percentage of common salt is exhibited in the following table.

Table XV.

Experiments with Cochituate Water and graduated Solutions of Common Salt.

Bars and volumes as in the foregoing experiments. No concentration. Bars resting on the bottom of the tubes.

Days.	Pure Cochituate.	Cochituate and $\frac{1}{100}$ of Chloride of Sodium.	Cochituate and $\frac{1}{1000}$ of Chloride of Sodium.	Cochituate and $\frac{1}{10000}$ of Chloride of Sodium.	Cochituate and $\frac{1}{100000}$ of Chloride of Sodium.
1	2.00	.20	.30	1.60	2.00
2	1.80	.10	.15	.60	1.20
3	.20	.10	.08	.08	.30
8	.30	2.50	1.20	.30	.50

These results show, —

1st. The immediate effect of the salt in preventing the action on lead by lessening the solvent power for air; and

2d. The influence of salt in dissolving the coat formed, by double decomposition, or by the formation of the double salt of the oxide and chloride; as shown in the last suite of results.

The preceding experiments, as a whole, go to *show that Cochituate water may be distributed through iron mains and leaden service-pipes with as little danger as Schuylkill, Croton, or Jamaica water.*

The consideration that was to give value to these determinations was that of the health of the citizens of Philadelphia, New York, and Boston, so far as it might be influenced by the waters served through lead in the respective cities. This was to be decided, as already intimated, by an appeal to the most enlightened testimony that could be furnished; that of eminent physicians of extensive practice in the localities where lead pipe is employed.

The following summary of opinions is chiefly compiled from the letters addressed to me, and published in the Appendix to the Water-Commissioners' Report of August 14th, 1848. They refer not only to the waters above mentioned, but to several other similar waters, and to some spring waters.

'In regard to the New York water-works, which have for several years supplied many thousands of families, Dr. Griscom, in a letter to Dr. Webster, dated Dec. 14, 1847, and appended to the Report of the Consulting Physicians, says, "*Nothing but lead pipe is now used in this city for the conveyance of water into, and within, the residences of the citizens.*"

'He states also, that, during the period of five or six years in which the Croton water has been used by a population of nearly 400,000 persons, he has had no knowledge of any evil consequences which could be attributed to the use of the lead pipe. He states, in addition, that he laid Dr. Webster's inquiry before "the Academy of Medicine, the largest professional body" in the city, and requested that, "if any gentleman had ever known or heard of any evil results from the use of lead pipes," he would communicate the facts. "No intimation of such results was offered," and a negative answer had been also given by several of the practitioners in the city, with whom the writer had personally conferred. . . . . .

'The water-works of the city of Philadelphia have been in successful operation for more than twenty-five years, and they have afforded a wide field of experience, which has been of great value to the directors of other similar works. . . . . . B. H. Coates, M. D., physician to the Pennsylvania Hospital, Philadelphia, after remarking that, in twelve years' service in the Hospital, he had not known any case of disease from the poison of lead, not distinctly traceable to some other source than the use of water drawn from leaden pipes, adds, — "We certainly feel ourselves quite safe in the employment of the water from Fairmount, and no case of lead disease from this cause is ever heard of."

'Professor Dunglison, of Jefferson Medical College, Pennsylvania, says, — "I have never witnessed the slightest effect from the use of the waters of the Schuylkill, conveyed in leaden service-pipes, which could lead me to suppose that there was any injurious impregnation." He quotes the remark of Professor Hare, that he had used the Schuylkill water conveyed in leaden pipes, in his laboratory in the University, for

more than twenty-five years, and had never perceived the slightest indication of the presence of the metal in it. Professor Dunglison adds, —"The results of all my observations in Philadelphia and elsewhere would lead me to express very confidently the belief, that leaden service-pipes, constantly filled, as they necessarily are, are entirely innocuous."'

In furtherance of this investigation, 'the Board of Consulting Physicians caused inquiries to be made in more than a hundred families, residing in Washington, Tremont, Pleasant, Warren, Essex, Harrison, Kneeland, Edinburgh, Oxford, Beach, Tyler, Hudson, South, Sea, Purchase, Summer, Atkinson, Charles, Cambridge, North Russell, Lowell, and other streets, who have used the water of Jamaica Pond drawn from leaden pipes, as common drink, for periods of from two to twenty years; and in no instance has any of the specific diseases attributable to lead been remembered to have existed in these families.' *

'In Baltimore, the distribution of water through leaden pipes is not found to be injurious to health. Dr. Aiken says, —"No case of lead poisoning has come to my knowledge, during a residence of thirteen years in Baltimore, arising from the use of our hydrant water. The lead pipes seem to answer the purpose very perfectly and very safely."

'Dr. McNaughton, of Albany, where leaden pipes are partially used for the distribution of water, states that his own family have, for a period of sixteen years, freely used, for all purposes, water introduced to his house, a distance of at least one hundred and seventy-five feet, through a leaden pipe, and they have never had, in that time, a case of lead or other colic. He has known no case of lead poisoning from the use of the Albany water-works, and he has been informed, on inquiry of some of the oldest physicians of the city, that they know of no such case.

'Dr. Brinsmade, of Troy, N. Y., where nearly all the pipes for the distribution of the water supplied by the city water-works about the yards and buildings are of lead, states that the water is used by nearly all the inhabitants for culinary purposes and for drink; and that in a large practice in the city, for the last fifteen years, he has never seen a case in which he suspected poisoning from lead, caused by the use of water passing through leaden pipes. A similar statement was made to Dr. Brinsmade by several of the most intelligent and

* *Report of Consulting Physicians to the City of Boston*, April 12, 1848.

experienced physicians of the city, and by the Superintendent of the Water-Works.

'Professor Hubbard, of Dartmouth College, where the inhabitants of the village have been supplied, for a period of twenty-six years, with water conveyed nearly two miles through a leaden pipe, and distributed through pipes of the same material, states, as the result of his own observation, and that of Professor Crosby for ten years, Professor Muzzy for sixteen years, and Professor Peaslee for eight years, that they have had no knowledge of lead poisoning, or disease of any sort, from the use of the water, and they speak highly of the healthfulness of the village. . . . . .

'In the village of New Boston, in the town of Lancaster, about two hundred inhabitants are supplied with water, conveyed through leaden pipes extending one and a half miles. Dr. Lincoln, who has been engaged in medical practice there more than twelve years, has known no disease which can be ascribed to the use of the water. No action of the water is perceptible upon the internal surface of the pipe, but the pipe is in many places much corroded externally, where laid down near stables and other buildings.

'The water of the London water-works is distributed from the houses in leaden pipes, and is usually preserved for use in tanks lined with lead, and without complaint of any injurious effects from the metal. On this subject, Professor Graham, of University College, London, in reply to an inquiry, says, — "The point has been settled here by long experience. *Lead alone is used to conduct the water from the street main into the houses*, or for service-pipes. No evil is experienced in London, either from these pipes, or the leaden cisterns. Yet, as the latter are filled in general only twice a week, the water must remain in them for several days." . . . . .

'Leaden pipes are extensively used in Paris for the distribution of the water of the Seine and the Ourq to the places of delivery for the supply of families, without injury to health. M. Tanquerel, in his elaborate treatise on lead diseases, lately republished in this country by Dr. Dana, discovered no indications of those diseases among the citizens of Paris, from drinking water supplied through leaden pipes.'

The decision of this question does not depend upon the presence or absence of a minute quantity of lead in water that has been standing a given length of time in leaden pipes, or upon the *absolute* freedom

from corrosion of pipes long in use. For if a certain quantity, more or less, has found its way into the human system in the every-day regular use of Croton and Schuylkill waters, then must the human system be capable of sustaining without injury this quantity ; and the possibility of receiving an equal quantity hereafter by those who drink Cochituate water may be contemplated without solicitude, since the experiment has been made.* Nevertheless, examinations for lead have been made in many well-waters, and in Croton, Jamaica, Schuylkill, and Troy waters, and Dedham spring water. The results follow.

Table XVI.

Determinations of Lead in Well-waters served through Leaden Pipes in Cambridge.

	Volume.	Hours Exposed.	Reduced Volume.	Sulphide of Lead.
				gr.
a	100cc.	36	10cc.	0.000
"	200	36	10	0.000
"	300	36	10	0.000
b	500	12	16	0.000
c	100	12	10	Precipitate.
"	50	12	10	"
"	40	12	10	"
"	30	12	10	0.000
	gallon	12	10	0.100
d	500cc.	12	5	0.000
e	100	12	5	Precipitate.
	gallon	12		0.080
f	300cc.	12	5	Precipitate.
	gallon	12		0.0004
g	500cc.	12	20	0.000
h	200	36	5	0.00005
	gallon			0.00113
i	300cc.	12	10	0.0009
	gallon			0.0136

Well in Boston. — 200cc., first drawn in the morning, gave, when concentrated to 5cc., 0.00003gr. = 0.00068gr. in a gallon. Dr. Charles T. Jackson has detected lead in a well-water in Waltham.

Well in Dedham. — 100cc. water standing over night in the pipe serving from the reservoir supplied by a forcing-pump, concentrated to 5cc., gave a trace of lead.

Water supplied from the spring in Dedham, which is known to

* To this point more particular reference will hereafter be made.

have corroded leaden pipes, and poisoned at least one individual.— 100cc., at rest twelve hours in leaden pipe several years in use, gave 0.00003gr. = 0.0013gr. in a gallon. Several years since, my friend, Dr. Webster, examined some of this water from the pipes of the gentleman who was made ill, and detected lead, without concentration, by treatment with sulphide of ammonium.* This branch pipe was 150 feet in length. The main pipe, two inches in diameter, is about three quarters of a mile long. This pipe must be capable of holding a gallon in a little more than seven and one third feet, or 540 gallons in its whole length. Thus, the entire morning draught of *spring water* of each family had ordinarily been at rest twelve hours in the main and lateral pipes. In some instances it had doubtless been longer at rest; and yet, so far as I have been informed, but one well-established case of lead disease is known to have occurred from the use of this water.

Table XVII.

Determinations of Lead in the Croton Water of New York.

Drawn, after thirty-six hours' exposure, from leaden pipes, at seven different localities, in the neighbourhood of John Street.

Bottles.	Volume.		Volume.				
1.	500cc.	reduced to	10cc.	gave,	of Sulphide	of Lead,	00
2.	"	"	"	"	"	"	00
3.	"	"	"	"	"	"	00
4.	"	"	"	"	"	"	00
5.	"	"	"	"	"	"	00
6.	"	"	"	"	"	"	00
7.	"	"	"	"	"	"	trace.

1000cc. derived from bottles 1, 2, and 3, concentrated to 10cc., gave, with hydrosulphuric acid, a precipitate which, ignited with saltpetre and redissolved, gave, with bichromate of potassa and hydrosulphuric acid, distinct precipitates of lead. The whole quantity equalled about 0.0001gr., or for a gallon 0.00045gr.

Determination of Lead in the Schuylkill Water of Philadelphia.

According to Professor Booth, 100 apothecaries' ounces, after exposure 36 hours in leaden pipe, a year and a half in use, concentrated

* Such was the quantity of lead in solution, that a white film (of carbonate and hydrate of lead) rose to the surface of this water, after being drawn a short time.

to the bulk of half an ounce, gave not the slightest discoloration after transmitting hydrosulphuric acid through it for an hour.

Troy Reservoir Water.

2000cc., 24 hours at rest in leaden pipes several years in use, gave, when concentrated to one hundredth of its volume, no trace of lead.

TABLE XVIII.

Determinations of Lead in Jamaica Water served through leaden Pipes in the City of Boston.

April 13th.	Exposed to the Lead.			Gave of Sulphide of Lead.
No. 6 Hudson Street,	200cc.,	12 hours,	reduced to 20cc.	00
No. 10 " "	"	"	" "	00
No. 98 " "	"	"	" "	00
No. 800 Washington Street,	"	"	" "	00
No. 10 Tyler Street,	"	"	" "	00

April 13th. Worcester Railroad Depot, 1000cc., exposed to the lead 36 hours, reduced to 20cc. gave, of sulphide of lead, 00gr.

June 19th. Worcester Railroad Depot, 500cc., exposed to the lead 36 hours, reduced to 5cc., gave, of sulphide of lead, 0.00002gr.* = 0.00018gr. in a gallon.

The magnitude of this quantity, and the influence its known presence in a water should have, may be over-estimated.

500 cubic centimetres contain 0.00002gr.
1000 " " " 0.00004gr.

Wiesbaden water contains of arsenious acid, in 1000cc., 0.00045gr.,† —a quantity more than ten times as great as the lead in Jamaica water, —and yet this water is renowned for its medicinal virtues. It may be said, that the arsenic is in combination with oxide of iron. Chevallier and Gobley have come to the conclusion, that its occurrence in springs is not dependent upon the presence of iron.‡ It is found in water whose character is determined by the presence of carbonic acid or sulphates. This body occurs in *solution* in waters from nine mineral springs in France. Its occurrence in Germany has been recognized, among others, by Will.§ Tripier found it in Algiers.

* Precipitate ignited, redissolved, and re-precipitated.
† *Compt. Rend.*, Tom. XXIII., pp. 612–615, 634, 635.
‡ *Journ. de Ph. et de Ch.*, 3 Ser., Tom. XIII., pp. 324–333.
§ *Ann. der Chem. und Pharm.*, LXI., pp. 192–204.

The appearance of leaden pipes taken up after several years' use, in New York, is what might have been expected. I have examined twelve pieces from as many different localities. Most of the specimens that had been in use for only one and two years were covered with a bluish-gray coat, and some of them could scarcely be distinguished from ordinary pipe for sale in the shops. A specimen in use five years is coated with a transparent, exceedingly thin, reddish-brown film, apparently composed of organic matter, oxide of lead, and oxide of iron. The crystalline laminæ upon the inner surface, characteristic of new pipe, are to be seen with the utmost distinctness, and present, with the exception of the coating, no appearance distinguishing it from new pipe.

Jamaica pipe, in use from fifteen to twenty years, is coated with a thick, reddish coat, which, when dry, may be readily disengaged, and in one specimen examined shows traces of slight corrosion beneath. The corrosion from without was such as to have nearly eaten through in some places. The lead of this pipe contained great proportions of antimony where corrosion occurred, but no sulphide of lead, which, I am informed, occurs in much lead pipe.

Pipe employed to conduct Dedham spring water is internally corroded, and presents at intervals deep depressions, the result of more extreme local action. Pipe of one well in Cambridge is appreciably corroded. Pipe of wells in Boston is frequently consumed in periods of from six to eighteen months.

The above results and observations show, that, —

1st. Many well-waters, in a space of time comparatively short, act on lead. This has been fully established by the researches of Dr. Dana * in this country, and by observations in England.

2d. That, except after longer exposure than will ordinarily occur in actual use, the amount of lead coming into solution in Croton, Schuylkill, or Jamaica waters is too small to occasion any solicitude.

Hence it may be inferred from the above, and from the great similarity of Cochituate to Jamaica, Croton, and Schuylkill waters, in its relations to lead, that *the quantity of lead that will be dissolved in Cochituate water in actual service will, for all practical purposes, be of no moment.*

Method of determining small Quantities of Lead.

The recognition and quantitative determination of very minute

* Appendix to Tanquerel, by Dana.

quantities are not always without difficulty; where many and rapid determinations are required, the processes of gathering upon a filter, washing, drying, igniting, and weighing consume far too much time, and are sometimes less accurate than other and more indirect methods.

That which I have employed is based upon the mode of analyzing silver coin proposed by Gay-Lussac,* and adopted quite universally at mints. The same general method has been extended by Gay-Lussac to ascertain the strength of alkalies and bleaching-powder. It is employed with protosulphate of iron and subchloride of mercury for the latter purpose. It is the method of graduated solutions.

A gramme of lead in the form of the acetate (common sugar of lead), which contains three atoms of water, is dissolved in 100 grammes or parts of distilled water. This constitutes solution No. 1.

Ten parts of this solution are diluted with 90 parts of water to make solution No. 2.

Ten parts of solution No. 2, diluted with 90 parts of water, make solution No. 3.

In the same manner solutions No. 4, No. 5, and No. 6 are prepared.

Ten parts of each solution are placed in corresponding test-tubes (about six inches long, five eighths of an inch wide, and closed at one end), and hydrosulphuric acid transmitted through them till the liquid, first blackened by the formation of sulphide of lead, becomes clear.

Test-tube No. 1 contains one tenth of a gramme of lead in the form of sulphide, — a black powder at the bottom.

Test-tube No. 2 contains one hundredth of a gramme.

No. 3, one thousandth.

No. 4, one ten-thousandth.

No. 5, one hundred-thousandth.

No. 6 yielded no precipitate without concentration.

Each succeeding precipitate in the series, setting aside a slight allowance to be made on account of solubility, was one tenth as voluminous as the one above.

Having prepared this scale of quantities, it is required to determine the amount of lead in a given diluted solution. An experiment is made to ascertain if the quantity be large enough to give a direct precipitate with sulphide of ammonium. This being decided in the negative, fifty cubic centimetres or grammes of water (corresponding with fifty parts of the scale of solutions) are carefully evaporated to dryness and ignit-

* *Annales de Chemie et de Physique.*

ed in a small porcellain capsule, to expel any organic matter that may have been present, moistened with nitric acid, and then warmed, with the addition of acetic acid and water, till the volume becomes ten cubic centimetres. A drop of acetate of potassa is then added, and then hydrosulphuric acid gas transmitted through the solution.

A precipitate results, or it does not. If it does, to know its value or the amount of lead it contains, the scale is resorted to. Though it might rarely be possible to identify it with either one of two precipitates in the scale, there could be no difficulty in deciding between which two it should fall, or nearest to which one of two it should be placed.

If fifty cubic centimetres thus treated yielded no precipitate, one hundred cubic centimetres were evaporated to dryness, and the residue similarly treated. If this failed, five hundred cubic centimetres were taken, and in some instances more, and the same course pursued.

It was natural to suppose that the presence of foreign bodies, such as occur in natural waters, might embarrass the precipitation. This led to the preparation of a series of graduated solutions of lead, with all the common salts occurring in waters, from the reagents in my laboratory. They were similarly treated with acetate of potassa, free acetic acid, and a stream of hydrosulphuric acid, and though it was possible to see differences in the amounts of the precipitates, they fell very greatly within the differences between the successive members of the graduated series.

The precipitates in the experiments with bars of lead, the results of which are given in the preceding tables, were estimated from this scale. They were, however, not ignited and redissolved, as in the examination of waters exposed in lead pipe, and the numbers were intended, as already remarked, to express only relative values.

Influence of Nitrates.

Although medical testimony and public sentiment were conclusive upon the subject of the health of our larger cities, so far as it might be influenced by the lead contained in the reservoir-waters used for culinary and general purposes, it was equally certain that individuals had been poisoned from drinking the waters of wells, and in one case, at least, from drinking water from a spring.

It was obvious, therefore, that between these two classes, river, lake, pond, and open reservoir waters on the one hand, and well and some spring waters on the other, there must be differences in their relations to lead.

Experiments were made with well-water, and at the same time with the river and lake waters in my possession. The following result shows with what success.

TABLE XIX.

Days.	Well-water.	Cochituate.	Fairmount.
3	1.00	1.00	.15
5	.20	.00	.60
6	.30	.50	.00
7	.10	.00	.00
8	.00	.05	.00
10	.50	.00	.00
11	.00	.00	.00

The bars rested on the bottoms of the tubes, and the waters had been some time standing in sunlight. These experiments threw little light upon the subject. The differences in favor of the Cochituate and Fairmount, as compared with a well-water known to act vigorously on lead pipe, were too inconsiderable to be worthy of notice. These waters contained in 500cc.

	Of Solid Residue.	Of Organic Matter.	Of Inorganic Matter.
Well water,	0.1380gr.	0.0540gr.	0.0840gr.
Cochituate,	0.0267	0.0122	0.0145
Fairmount,	0.3007	0.1032	0.1975

On comparing these, it will be seen that the water which contained the most solid residue acted least on lead, and that the action of that which contained least solid residue was next in order.

The comparison of the analyses of waters made by different individuals led to no satisfactory results. Ingredients that might have been presumed to be in all had in some cases not been recognized. The only large suite of analyses made by a single individual first fell under my eye in the early part of June of 1848. In the following table are compared the average total amounts of inorganic matters, and also the relative amounts of the more prominent salts, in three wells, six springs, and six rivers, as determined by Deville.*

	Total.	Nitrates.	Chlorides.	Sulphates.	Carbonates.
Wells,	6455	1701	650	1394	2291
Springs,	3344	86	77	365	2336
Rivers,	1949	65	38	157	1185

* *Ann. de Chem. et de Phys.*, 3e Série, Tom. XXIII. pp. 33–47.

The compounds of sulphuric and carbonic acids with oxide of lead are eminently insoluble. The chlorides are less insoluble, and the nitrates are highly soluble.* The contrast between the quantities of nitrates in well and river waters suggested the experiment with lead and graduated solutions of saltpetre.† The results follow.

TABLE XX.

Days.	Pure Cochituate.	Cochituate and $\frac{1}{1000}$ of Saltpetre.	Cochituate and $\frac{1}{10000}$ of Saltpetre.	Cochituate and $\frac{1}{100000}$ of Saltpetre.	Cochituate and $\frac{1}{1000000}$ of Saltpetre.
1	1.00	1.00	2.25	0.75	0.50
2					
3	0.00	2.00	1.00	0.50	0.10
4	0.50	2.00	0.25	0.10	0.10
5	0.00	2.50	1.00	0.30	0.20
6	0.05	2.50	0.50	0.30	0.00
7					
8	0.00	2.00	0.80	0.05	0.00
9	0.00	1.80	0.70	0.00	0.00

TABLE XXI.

Days.	Pure Fairmount.	Fairmount and $\frac{1}{1000}$ of Saltpetre.	Fairmount and $\frac{1}{10000}$ of Saltpetre.	Fairmount and $\frac{1}{100000}$ of Saltpetre.	Fairmount and $\frac{1}{1000000}$ of Saltpetre.
1	0.15	1.00	0.80	0.80	0.80
2					
3	0.60	3.00	1.25	0.25	0.20
4	0.00	1.80	0.50	0.00	0.00
5	0.00	2.25	1.50	0.40	0.10
6	0.00	1.80	0.80	0.05	0.00
7					
8	0.00	2.50	0.80	0.20	0.05
9	0.00	1.80	0.80	0.20	0.00
10	0.00	1.80	0.80	0.20	0.10
11	0.00	1.20	0.80	0.00	0.00

* Sulphate of lead is soluble in not less than 15000 parts of water. GMELIN. — Carbonate of lead requires 50551 parts of water. FRESENIUS, *Ann. der Chem. und Phar.*, LIX., S. 117 - 128. — Chloride of lead requires 135 parts of pure water, 534 of water containing chloride of calcium, and 1636 of water containing hydrochloric acid. BISCHOF. — Nitrate of lead dissolves in 1.989 parts of water at 63° Fahr. KARSTEN. — A solution of saltpetre containing 39 parts to 100 of water will still dissolve 110 parts of nitrate of lead. — GMELIN.

† O'Henry found nitrates in mineral spring-water in 1839. — *Journ. de Pharm.*, Dec., 1838, pp. 634 - 637.

Liebig found nitrates in twelve wells in Giessen, and none in the wells of the surrounding country, by experiments made in 1827. "This fact has been noticed

The mode of action of the saltpetre has been the subject of experiment. I had previously exposed bright bars of lead to natural waters containing traces of nitrates, which were deprived of air and sealed in glass flasks Months had produced no action upon the lead, and had conducted to the opinion, that lead was not acted upon by nitrates in natural waters.

As the reaction of the Cochituate or Fairmount water was perfectly neutral, the decomposition of the saltpetre by free acid, which should expose the lead to uncombined nitric acid, was not possible.

Fresenius had observed that the carbonate of lead was less soluble in water containing nitrate of ammonia and ammonia than in pure water. I was aware that alkaline chlorides promoted the solution of certain lead compounds, and it occurred to me that they might be more soluble in waters from the presence of nitrate of potassa, soda, or lime.

In changing the waters, from day to day, exposure to the air would furnish the oxygen and carbonic acid more directly than the absorption from the surface, for the formation of the hydrated oxide and carbonate, and these might to a slight extent, it seemed possible, experience decomposition with the saltpetre.

The decision of this point rested upon the following experiments.

1. A solution of saltpetre, the usual laboratory reagent, was poured upon a quantity of common white lead, and, after repeated agitation and alternate rest, filtered off and tested with hydrosulphuric acid for lead. There followed an instantaneous, distinct, though not large, precipitate of sulphide of lead.

There was an objection to the experiment. White lead prepared from the acetate might not be altogether free from acetate of lead. This, if present, might be brought into solution by the nitrate of potassa.

2. To settle this point, a portion was carefully ignited upon platinum. Had there been appreciable acetic acid, the mass would have more or less blackened, or would have revealed to the sense of smell some evidence of its presence. It gave no indication whatever.

by Berzelius in Europe. I," says Dr. Dana, " have confirmed it in the water of a great number of wells in Lowell." — *Appendix to Tanquerel*, p. 367.

Guyton Morveau, most of whose labors belong to the last century, mentions saltpetre as one of the salts denominated by him protecting in its influence on leadon pipes, when seeking to find the value as protectors of the different salts occurring in natural waters. — Christison.

Dr. Dana has ascribed a prominent place to nitrates and chlorides in the action of well-waters upon lead. — *Appendix to Tanquerel.*

Experiments with graduated solutions of common salt were made. See p. 17.

3. A quantity of the white lead was then treated with sulphuric acid and alcohol in a test-tube, in the usual manner for detecting acetic acid by the formation of acetic ether. This failed to give a trace of acetic acid. The quantity of white lead was small.

4. Four ounces of white lead were then boiled three hours with a large measure of diluted soda, filtered, concentrated, and treated with sulphuric acid and alcohol as before. It yielded no distinct trace of acetic acid.

5. To meet the question fully, and give to the experiment the advantage of the nascent state which in actual practice must occur, and to give to the view an entirely unobjectionable foundation, I added to a solution of nitrate of lead, first, potassa, which threw down a hydrate of lead, and then carbonate of potassa, which threw down a carbonate of lead, until the solution yielded an alkaline reaction. There were then hydrate and carbonate of lead in the precipitate, and nitrate of potassa, carbonate of potassa, and if any lead, a nitrate of lead in solution. The liquor was filtered, and upon adding hydrosulphuric acid to the filtrate, I obtained a precipitate of the black sulphide, more voluminous than in the first experiment with white lead and a solution of saltpetre.

6. Soda and carbonate of soda gave the same reaction.

7. Nitrate of lime in solution gave the same reaction as nitrate of potassa.

My attention has been drawn by a friend to the following sentence in Berzelius: — 'When nitrate of lime is boiled with carbonate of lead, the oxide of lead is dissolved, while the carbonate of lime is deposited.' *

If with the aid of heat such decomposition results, it might be conceived that, favored by the nascent condition, quantity, and time, there might be to some small extent a corresponding decomposition.

The first was the principal experiment bearing on this point made at the date of my last letter to the Water-Commissioners, and upon this experiment, and the known solubility of the nitrate, I ascribed the increased action of water consequent upon the addition of nitrates to a slight double decomposition. It had been ascribed by Dr. Dana † to

* 'Lorsqu'on fait boullir du nitrate calcique avec du carbonate plombique il se dissout de l'oxyde plombique tandis que le carbonate calcique reste.' — *Traité de Chemie*, 1847, Tom. IV. p. 91.

† *Report of the Joint Special Committee of City of Lowell*, Aug., 1842, pp. 8 - 11.

the conversion of the protoxide of iron, in solution as protosulphate, into the peroxide, by which he conceived there would be free sulphuric acid, and therefore free nitric acid, in water containing protosulphate of iron and nitrates.*

This explanation would not apply to the action of neutral waters, or of those containing no protosalts of iron, though nitrates were present.

The whole subject has undergone a more thorough examination. The conclusion that nitrates are not reduced by lead I have found to be erroneous; for experiment has shown that upon boiling a strong solution of nitrate of potash to expel the air, and introducing a bar of bright lead, it became immediately coated with suboxide of lead, and this without the evolution of gas. There had been a partial reduction of the nitric acid. Upon testing the solution with hydrosulphuric acid, it gave, after long digestion, but a faint discoloration. Upon pouring off the liquor and adding to it oxide of lead, and continuing the digestion, a large quantity of lead was dissolved, which in 66cc. gave of sulphide of lead 0.0106gr. = 0.7296gr. in a gallon. The solution reacted strongly alkaline.

As the only known inorganic salts of nitrous acid are its compounds with lead, it was probable that, upon the reduction of the nitric acid to nitrous acid, it had abandoned the potash to unite with the oxide of lead, or a basic soluble salt had been formed, in which potash was present.

Upon examining the nitrate of potash employed as a reagent in the first experiment, and which had been purchased for this purpose because it was labelled *pure*, it was found to contain alkaline chlorides, — a circumstance to which the lead in the first experiment might in part be ascribed. A repetition of it with pure nitrate of potash and the hydrate and carbonate of lead, prepared by exposing lead to distilled water in an open vessel, gave but a faint discoloration with hydrosulphuric acid. I am inclined to ascribe to the reduction of the nitric acid much the greater part in the action of nitrates upon lead.

* The change that takes place when a solution of copperas is exposed to the air may be thus represented: — $4\,(Fe\,O, SO_3) + 2O = Fe_2\,O_3, 3\,S\,O_3 + Fe_2\,O_3, S\,O_3$. The latter compound is insoluble in water. GMELIN. — The constitution of the precipitate, according to MITSCHERLICH and SCHEERER, is $2\,Fe_2\,O_3, S\,O_3 + 3\,H\,O$. WITTSTEIN (*Buch. Rep.*, 3 R., Bd. I., S. 182–189) gives it as $2\,Fe_2\,O_3 + 3\,SO_3 + 8\,H\,O$. An acid salt remains in solution, which is probably what Dr. Dana would have understood from the statement that the above decomposition produces *free* sulphuric acid.

Action of Air.

The importance of air in order to the action of a water upon lead has been intimated in the results already recorded. The following experiments confirm the observations of Yorke, Bonsdorff, and others, and, more recently, of Dr. Hayes, as expressed in his Report to the Consulting Physicians.*

1*st experiment.* — June 17th. An apparatus consisting of a half-gill flask, containing lead scrapings and Cochituate water, filled to half its depth, the lead all below the surface of the water, was connected by a tube, bent twice at right angles, with a vessel of mercury. The cork uniting the tube and the flask was carefully covered with sealing-wax. If, now, in the oxidation of the lead, oxygen should be withdrawn from the space above the water, mercury would rise to occupy its place. The mercury had risen, June 19th, three fourths of an inch; July 1st, four inches; July 22d, six inches; and in August the mercury passed over into the flask.

Another similar apparatus prepared on the 16th of May showed, on the 10th of August, mercury at a height of 6½ inches.

2*d experiment.* — A flask of a half-gill capacity was filled to two thirds its depth with distilled water, and boiled five minutes. While hot, and without delay, bars of bright lead were added, and the flask filled from another flask containing distilled water that had been boiling an equal length of time. In this condition a nicely-fitting cork was adjusted to the neck, and expeditiously sealed, so as to prevent the admission of air.

Another flask was filled in the same manner with Cochituate water, and sealed. Both are in possession still. The bar in distilled water is quite as bright as when immersed, except around the end in contact with the glass, which has become a little coated. The bar in Cochituate water was bright for some months, but has at length become slightly dimmed in small patches, which may be attributed to the less complete expulsion of the air by boiling, or the less accurate stopping of the flask, though at the time the experiment was made both were regarded as unobjectionable.

The following experiment shows how much is due to a change of water. The bars in the Cochituate remained quite bright, and those in the other waters were but slightly coated.

* *Report of Consulting Physicians*, Boston, 1848, p. 23.

Two bars in 15cc. for thirteen consecutive days, without changing the water, gave, in Cochituate, 0.500gr.; Croton, 0.500gr.; Fairmount, 0.500gr.; Jamaica, 1.000gr.

These experiments seemed to show that, without a renewal of the air, the action nearly or quite ceases after a short time.

Professor Silliman, Jr., made a similar observation in his experiments with the various waters submitted to him for analysis by the Water Commissioners in 1845. He used a large volume of water, and yet the bar remained quite bright. There was no *alternate exposure to water and air.*

Christison remarks, that, while certain waters might doubtless be kept with safety in leaden cisterns, the covers of the cisterns should not be of lead, but of wood, since the moisture condensing on them, furnishing, as he observes, *pure* water, would act on the lead, and the product falling would poison the water. The joint action of air and water is here presented under exceedingly favorable circumstances. The corrosion of cisterns along the line where air and water meet might be expected.

It will be readily seen, from considering the important part air plays, how rain-water must act with great vigor upon lead. It contains air, and is surrounded by air, and, aside from temperature, could not be more favorably constituted for acting upon lead.

The well-known prevalence of lead maladies in Amsterdam, while leaden roofs were in use, and the restoration of health on their replacement with tile, find here a ready explanation.

Dr. Dana has recorded an experiment with rain-water, which furnishes a valuable confirmation of what is stated above.*

In a series of experiments with lead pipe of considerable length, if an interval of half a minute, or even less, occurred between the emptying of the pipe and refilling, there was invariably found lead in the water. This has been observed on a large scale in the practical service of lead pipe. Where from any cause the pipes have been empty for a length of time and then filled, the first water drawn contains a very considerable quantity of lead.

In the experiments of the preceding tables, the tubes intended to receive the bars were previously filled, and thus the transfer of the bar from one tube to another occupied scarcely a second of time. Even

* *Appendix to Tanquerel.*

this short period was doubtless adequate to provide for some of the oxidation which the bar experienced.*

Important as the office of air is, it is not adequate of itself to oxidate lead. A bar of lead scraped bright and placed in a desiccator over sulphuric acid remained undimmed for weeks, — during the whole time of the experiment.

Influence of Light and Organized Substances in Water.

It is a familiar fact, that well-water recently drawn and exposed to the light and warmth a short time loses much of its air, and becomes insipid. Count Rumford has made this fact the foundation of an important investigation. His conclusions in relation to the joint effect of sunlight and solid, miscible but insoluble substances in expelling the air from waters, and thus showing a difference between lake, river, pond, and reservoir waters, which are exposed to sunlight, and well or spring waters, which are concealed from it, are of great importance in this connection.†

I have made numerous experiments upon this subject, which, although still incomplete, taken in connection with the results of Count Rumford, go to establish the following positions: —

1st. Well waters contain more air in solution than lake, river, and pond waters, as a class.

2d. Sunlight and heat falling upon water containing solid insoluble substances, organic tissues, or pulverulent matter, expel a portion of the gases.

3d. The germs of animalculæ being present, oxygen will be given

* I see, in the time between the emptying and filling of leaden pipes employed in experimenting, the explanation of much of the discrepancy between the results of different experimenters. If to this be added the unequal exposures to warmth and light which have been permitted by those engaged in experimenting, I am persuaded that most of the differences in results will be fully accounted for.

† He exposed spring water, containing, in a series of experiments, weighed quantities of raw silk, poplar cotton, sheep's wool, eider-down, hare's fur, cotton-wool, ravellings of linen, and Conferva (hair-weed), to the sun's rays, and observed the quantity of air disengaged by each substance. It amounted in some cases to *one eighth* of the volume of water. *Philosophical Papers*, by Benjamin, Count Rumford, London, 1802, Vol. I. pp. 218–263.

The observations of Wöhler in 1843 (*Ann. der Chem. und Pharm.*, Bd. XLI., S. 121), and of Schultz in 1845 (*Journ. fur Prakt. Chem.*, Bd. XXXIV., S. 61–63, 1845), upon the evolution of oxygen from waters containing animalculæ and 'green plants,' under the influence of sunlight, were confirmations of some of the experimental results of Count Rumford.

out and immediately expelled, until the maximum of the solvent power for air by the given temperature be attained.

4th. On the withdrawal of sunlight and the reduction of the temperature, the animalculæ cease to evolve oxygen, and that which is in solution becomes the prey of the decaying organic matters present.

5th. The hydrogen of organic bodies (as Liebig has remarked) oxidates first. This position I have verified by a series of observations, to which I will here only refer.

The following experiment may be mentioned in this connection. Two clear glass globes of about four and a half inches in diameter, filled with waters from two wells in Cambridge, in one of which, after rest of twelve hours in leaden pipe, lead was detected, and in the other of which, after equal exposure, no lead was recognized, were placed in a window of south-southeast exposure. Into each globe a skein of silk weighing 1.25gr. was introduced; at the end of five days, the quantity of gas evolved was more than twice as great in that containing the well-water that acted on lead as in the other. No admeasurement of the quantity was attempted, for the following reason: I wished to know what would become of these gases, — the water containing organisms which must soon consume their supply of nutriment. In a period equal to the above, the gases were entirely absorbed, and after the lapse of a month, during which time there were several days of brilliant sunshine, no gases appeared.

An isolated experiment of this description cannot have much value. But it seemed to me worth recording, as sustaining what Liebig has remarked, that of the elements of organic bodies the hydrogen is more readily oxidated than the carbon, and as illustrating the decay of organic bodies in water.

Of the various popular reasons why lead should not be employed for distributing water, the following have been found not to be sustained by experiment or authority.

1. *The Galvanic Action of Iron and Lead.*

The effect of contact with iron, in most of its points of view, has been investigated. In diluted acids, *bright* lead in contact with iron is positive, — *coated* lead, *negative*. Yorke. — Diluted acid facilitates the solution of iron in contact with lead. Runge. — In strong nitric acid, iron, in connection with lead, is *positive*. Delarive. — In potash solution or lime-water, bright lead is positive to iron, but *oxidated*

or *coated* lead is *negative.* This is also true of these metals in a solution of saltpetre. YORKE. — It is also true in a solution of salammoniac. WETZLAR.

Thus in *acid*, *alkaline*, and *saline* solutions, — all the conditions in which Cochituate water can occur, — iron, if not at first, will, after a short interval, be the metal at whose expense the galvanic action will be sustained.

2. *The Action of Iron-Rust.*

It was natural to suppose that the moist iron-rust flowing from the mains into the leaden pipes might, by reduction to a lower oxide, promote the oxidation and solution of lead.

Bars of lead in contact with hydrated peroxide of iron, in open tubes, containing Cochituate, Croton, Jamaica, Fairmount, Albany, and Troy water, arranged on the 15th of May, gave, when tested on the 17th, 22d, and 27th of May, and 7th of June, with ferrocyanide of potassium, no indication of protoxide.

The same water in which nails were immersed, tested from time to time, gave occasional evidence of the presence of protoxide of iron.

I placed peroxide of iron and bright bars of lead in flasks of distilled and Cochituate water, and sealed them, on the 7th of last June. The flasks are in my possession still, and though the air was expelled only so much as boiling five minutes would accomplish, the bars of lead are quite as undimmed as on the day they were sealed up. It is scarcely necessary to state that the iron rust, in actual service, does not come in contact with *lead*, but with the suboxide, or other coat.*

3. *The Solubility of the Suboxide of Lead.*

I have been unable to procure the slightest trace of lead in water deprived of its air, after long contact with the suboxide of lead. Mitscherlich remarks of its insolubility.†

4. *The Action of Alkaline Chlorides upon Lead, in the Absence of Oxygen or Atmospheric Air.*

The following experiment was made and several times repeated by me with graduated solutions of common salt.

* Reference has been made to the experiments of Napier upon this point. He made *no experiments with peroxide* of iron, but with *neutral salts* of the peroxide, and he states distinctly that lead exposed to them a little while became coated, and that action *was thereafter arrested.* — *Lond., Edinb., and Dubl. Philos. Mag.*, May, 1844, pp. 365 – 370.

† *Lehrbuch der Chemie*, 2te Band, S. 511.

A flask of one gill capacity, containing a quantity of lead shavings, presenting an extent of surface comparatively great, was one third filled with a solution of common salt. This flask was connected by a tube, bent twice at right angles, with a cup of mercury. The cork, tube, and neck, at the connections, were carefully covered with sealing-wax, that the flask might be air-tight. So arranged, the flask was slightly warmed; the air thereby driven out was of course replaced with quicksilver, the upper surface of which, after the original temperature had been reëstablished, was marked. Now, if any decomposition of common salt occurred by the agency of lead, the chlorine would be freed from the sodium, the sodium would decompose the water, hydrogen would be set free, and the column of mercury depressed. Instead of any such result, the column of mercury regularly rose in every instance. An apparatus of this description, several months in action, is still preserved in my laboratory.

It might still have been said, that, had the flask been deprived of air, the lead would have been acted on by the simple chloride.

The experiment of lead and sea-water, in a flask deprived of air, has been made. The flask was sealed on the 25th of May last. The bar for a long time retained its perfect brightness, and is but very faintly dimmed at this late day, February 1, 1849.

5. *Action of Organic Matter.*

It has been conceived that organic matter might exert a deleterious influence. Experiments already recorded (p. 15) show that the presence of organic matter increases the protecting power of water which is to be transmitted through lead. If the quantity exceed one ten-thousandth of the weight of the water, precipitates of oxide of lead, united to organic matter, take place. Orfila has remarked the precipitation of the coloring matter from Burgundy by neutralizing it with litharge.*

Its influence in withdrawing the oxygen from solution has also been alluded to. In the important researches of Dr. Smith † upon the air and water of towns, it is mentioned that the presence of nitrates in the London water prevents the formation of organic matter, and that organic matter, in filtering through soils, becomes rapidly oxidated. Additional experiments bearing upon this point are recorded farther on.

Influence of Impurities in Water.

It is a prevailing conviction, that the more impure a water is, or, in

* *Toxicologie Générale*, Vol. I. p. 616. † *Proc. Brit. Ass. Athen.*, No. 1087.

general terms, the more salts it contains in solution, the less will be its action on lead.

The influence of sulphate of magnesia (epsom salts) and chloride of sodium (common salt) in distilled water was the subject of experiment.* The action, it will be seen, was more vigorous in distilled than in the impure waters.

TABLE XXII.

Experiments with Lead and Graduated Solutions of Sulphate of Magnesia (Epsom Salt).

Days.	Distilled Water.	Distilled Water and $\frac{1}{10000}$ of Epsom Salt.	Distilled Water and $\frac{1}{100000}$ of Epsom Salt.	Distilled Water and $\frac{1}{1000000}$ of Epsom Salt.
1	—	—	—	—
3	5.000	2.500	2.000	1.750
5	20.000	1.500	2.000	1.800
6	4.000	2.500	2.000	1.800
7	3.000	1.800	2.000	1.500
8	2.500	2.500	2.000	0.800
10	3.000	1.800	3.000	1.800
11	2.000	1.500	1.800	1.500
12	3.000	1.200	2.000	0.800
13	2.000	1.200	1.200	0.800

TABLE XXIII.

Experiments with Lead and Graduated Solutions of Chloride of Sodium.

Days.	Distilled Water.	Distilled Water and $\frac{1}{10000}$ of Salt.	Distilled Water and $\frac{1}{100000}$ of Salt.	Distilled Water and $\frac{1}{1000000}$ of Salt.
1	—	—	—	—
3	5.000	2.500	2.000	1.500
5	20.000	1.800	2.500	2.000
6	4.000	1.800	1.800	2.000
7	3.000	1.800	2.000	2.000
8	2.500	2.000	2.000	1.800
10	3.000	2.500	2.250	2.500
11	2.000	1.800	1.800	1.500
12	3.000	1.200	1.200	1.200
13	2.000	1.000	1.200	1.200

Coats that form on Lead.

In seeking to ascertain the nature of the protecting coat which

* Experiments with chloride of sodium and Cochituate water are recorded on p. 17.

forms in all the waters hitherto experimented with, the influence of organic matter was first considered.

500cc. of each of several waters were evaporated to dryness over a water-bath, ignited, and redissolved in an equal measure of distilled water. There remained a small insoluble residue, which readily dissolved, with effervescence, in hydrochloric or acetic acid, — indicating carbonate of lime. Bars of lead were exposed to these prepared solutions. A bluish-white coat formed upon the lead in each.

TABLE XXIV.

*Experiments with the several Waters deprived of their Organic Matter and Carbonate of Lime.**

Days.	Distilled Water.	Albany.	Cambridge.	Cochituate.	Croton.	Fairmount.	Jamaica.	Troy.
1	3.000	0.000	0.500	5.000	6.000	15.000	5.000	4.000
4	1.000	0.000	0.500	0.500	2.500	2.000	12.000	2.000
5	1.500	0.010	0.010	0.020	8.000	1.000	15.000	0.500
8	2.000	0.010	0.500	0.800	10.000	2.000	3.000	1.000
9	0.500	0.050	0.050	0.100	4.000	4.000	1.500	1.500
11	0.500	0.100	0.100	0.100	0.800	0.100	0.100	0.100
18	0.500	0.800	0.800	0.800	20.000	30.000	0.800	0.500
37	1.500	1.000	2.000	1.250	12.000	3.000	0.700	1.500
42	1.250	1.000	1.000	2.000	2.000	20.000	8.000	0.100
44	15.000	1.500	1.000	0.800	0.200	0.100	0.100	0.100
47	15.000	0.500	0.100	1.500	0.500	0.100	0.100	0.100
48	0.200	0.100	0.300	0.100	1.000	0.200	0.100	0.300
49	0.400	0.400	0.500	0.300	2.000	0.500	0.400	0.400
50	0.500	0.200	0.900	1.000	2.000	2.500	1.000	0.100
52	1.750	0.010	1.800	1.800	1.000	3.000	0.100	0.100

It will be seen, on comparing the results of their actions with those of the natural waters, that they are more protracted and vigorous, that they approach more nearly the action of distilled water, and that no protecting coat can be said to have formed.

Three kinds of coating upon lead have fallen under my notice: a bluish gray one, which, according to Winkelbleck, Mitscherlich, and others, is a simple suboxide; a reddish one, which formed in Croton, Schuylkill, and Jamaica waters; and a white one.

The coat of *suboxide* is insoluble in water. When the quantity of oxygen in solution in a given water is small, this coat will be first formed. It is the only one I have seen in Croton pipes less than two

* Professor Silliman, Jr., has remarked of the alkaline reaction which the redissolved residues gave. The reaction of the above solutions was not observed. In their extreme dilution, an alkaline reaction could not have been appreciable.

years in use. The addition to this coat of slimy organic matter, oxide of iron, and, to some extent, carbonate of lead, forms the *reddish* coat, the impermeable character of which, for all practical purposes, is illustrated in the appearance of Croton pipe five years in use, and already referred to. The *white* coat, it has been observed, consists chiefly of carbonates and sulphates.

Solubility of Oxide of Lead.

I have already noticed the contrariety of opinion upon the solubility of the oxide of lead. I have repeated the experiments of Yorke, and confirmed his results, and am, moreover, satisfied that, had Thompson and Philips concentrated the filtrates which they supposed to contain no lead, they would have detected it without difficulty.

A flask containing distilled water and lead shavings was corked and placed aside for a few days. A deposit of carbonate and hydrate of lead formed around and upon the lead shavings. The contents of the flask were carefully poured upon a double filter of Swedish paper, and the filtrate concentrated. It gave a distinct precipitate with hydrosulphuric acid.

Tea and Coffee Grounds unite with Lead in Solution.

It has been an occasion of surprise, that numerous families have for a long period employed well-water that corroded leaden pipe so rapidly as to require replacement in from six to eighteen months, and yet, so far as they or their physicians know, have suffered no illness attributable to the water. This fact suggested two considerations : —

1st. Are all lead compounds equally poisonous ?

2d. If so, is the quantity which finds its way into the organism sufficient to produce the maladies attributed to lead ?

It may be assumed that water flowing directly through a leaden pipe of an inch bore and not more than thirty feet in length will ordinarily be identical in constitution with that in the source from which it is drawn. That only which has been some time at rest would be expected to contain lead. Accordingly, there is more care that the water first drawn be thrown away. The first morning draught is usually in the form of tea or coffee.

The following experiments throw light upon this point.

To boiling water containing lead in solution tea was added, in the quantity usually taken in the preparation of the beverage (a gramme to 50cc.), the temperature maintained three minutes just below the boiling point, and the decoction filtered off.

The filtrate was evaporated to dryness, ignited, redissolved, and the precipitate with hydrosulphuric acid made and estimated as already described.

I. 50cc. of lead solution, containing one thousandth of its weight of lead, with 1gr. of black tea, lost ninety-nine hundredths of its lead.

Originally present,	0.05gr. of lead.
After separation from the grounds,	0.0005 "

II. 55cc. of solution containing one tenth as much lead as the above, with the above quantity of tea, lost more than eleven twelfths of its lead.

Originally present in solution,	0.005gr. of lead.
After separation from the grounds,	0.0004 "

The experiments with coffee yielded the following results: —

I. 50cc. of lead solution, containing one thousandth of its weight of lead, with 10cc. of coffee-grounds, were boiled three minutes, and the decoction poured off. The residue was drained through Swedish filtering-paper, the filtrate added to the liquor poured off, and evaporated to dryness, ignited, redissolved, treated with hydrosulphuric acid, and the precipitate estimated as before.

It had lost more than forty-nine fiftieths of the lead.

Originally in solution,	0.05gr. of lead.
After separation from the grounds,	0.0009 "

II. 50cc. of solution, containing one tenth as much lead as that in the last experiment, were boiled with 5cc. of coffee-grounds, and treated as above. It had lost more than eleven twelfths of its lead.

Originally in solution,	0.005gr. of lead.
After separation from the grounds,	0.0005 "

These results contribute to account for the circumstance mentioned above.*

* It may not be unacceptable to present here an idea of the degree of danger to which persons drinking Croton and Fairmount or Cochituate water (after the first few weeks of use) are exposed.

How much lead is required to produce a given disease?

In Pereira's *Materia Medica*, it is stated that doses of acetate of lead, of from one to ten grains, 'repeated twice or thrice daily,' are given for certain diseases. The maximum per diem is thirty grains; the minimum, two grains; the medium, sixteen grains, — more than a gramme. More than half of the common sugar of lead, with three atoms of water, is lead. Of this, it is advised to give a half-gramme daily, for particular cases. At this rate, in ten days five grammes would have been taken.

From this amount it would seem that medical practice has recorded no injurious

Other Materials than Lead for Service-pipes.

I have remarked that this investigation was instituted chiefly with a view to determine the trustworthiness of lead. Experiments have, how-

effects. Let it be presumed, however, that this quantity, taken in the absence of illness, and distributed through a long period, may in some instances be productive of disease. If we take the blood, muscles, and other organs of a man who has been sacrificed to lead maladies, we may ascertain the amount of lead in the system at the time of death (or approximately so), and by examining the fæces, the minimum, at least, of what was received daily, or in a period a little longer, and from these data some estimate may be formed of how much lead would be required to produce a given disease.

Fortunately an instance is on record. (*Ann. d'Hygiène*, 1840, Juill., pp. 180–188.)

In a case of *encephalopathy*, investigated after death by Devergie, quantitative determinations of the lead in several organs, in the blood, and in the fæces, were made. They contained of sulphate of lead, the form in which the analyses were made : —

Kidneys, 8oz. 1dr.	0.002 gramme.
Muscle, 12oz.	0.026 "
Blood, 7oz.	0.050 "
Stomach, total, ...	0.030 "
Lungs, "	trace.
Gall bladder and bile, total, ...	0.004 "
Urinary bladder, "	0.005 "

Considering the *muscles* and *blood* as composing the larger bulk of the organism, and converting the sulphate of lead into lead, we have, assuming the blood to be 25lbs., and the muscles to be 60lbs.,

	Lead.
In the blood, ...	1.560 grammes.
" muscles, ...	1.040 "

The quantities of lead in the stomach and intestines were large : as there is no *quantitative* guide in relation to the latter in the results of Devergic, we may perhaps safely assume that all the lead in them and in all the organs and juices beside, exclusive of the muscles and blood, may have been half that of the blood, = 0.780 gramme. The whole body may then be considered, at a minimum, to have had 3.380 grammes of lead.

A definite amount of lead, in this case, was found in the excrements, as might be conceived from its combining with the chyme, without going through the round of the circulation. Besides this, another quantity was secreted from the kidneys and liver, as both these organs contained it.

Let it be granted that two thirds of the whole quantity of lead received in a very diluted solution — such as Jamaica water that has been standing thirty-six hours in leaden pipe — is detained in the system of an individual drinking it.

$3.380 + 1.690 = 5.070$ grammes equals the quantity, with this supposition (which cannot err unfavorably to those who disapprove of leaden pipes), necessary to produce a disease such as that mentioned above; that is, necessary in

ever, to some extent, been made with other substances. The general conditions have been observed in experimenting with them that had

order that 3.380 grammes, the quantity found in the deceased body, may enter the system.

Now how much Jamaica water, that had been at rest thirty-six hours in leaden pipe, must be drunk, to receive 5.070 *grammes of lead?*

Such water from the Worcester Railroad Depot yielded, in 500cc., 0.00002gr. of lead. A gallon, at this rate, would have furnished 0.00018gr.

The quantity to be drunk, given by division of 5.070 *by* 0.00018, *is* 28,166 *gallons.*

Were an individual to drink a gallon each day of water so exposed, he would consume the above quantity in *seventy-six years.*

The water will ordinarily not be at rest more than twelve hours. The period required for the above task would therefore be increased threefold, making it *two hundred and twenty-eight years.*

But for quite as much as one half of the time, the first draught from the pipe will have been appropriated to other purposes, and the morning beverage will be untainted. This doubles the above period, making it *four hundred and fifty-six years.*

But, again, the pipe in general use being five eighths of an inch in diameter, of which fifty feet will be more than the average length of pipe employed in private residences, it will never be possible to expose more than two thirds of a gallon to the action of the water. This consideration requires an increase of the above period one half, — to *six hundred and eighty-four years.*

Again, in the preparation of tea and coffee, the morning beverages would lose a large proportion of their lead. Grant that it be but three fourths, and the period becomes *two thousand seven hundred and thirty-six years.*

But still again, these two thirds of a gallon must ordinarily be shared between from two to eight persons, — five on an average ; that is, any member of a family of this number would receive about one fifth of it, and in order to produce the disease mentioned in the outset by drinking such water, it would be required to live *thirteen thousand six hundred and eighty years.*

Even this is not placing the want of any foundation for solicitude in its strongest light.

It will be seen by referring to the analyses of Devergie, that the fæces contained 0.023gr. of sulphate of lead. Converting this sulphate into lead, in round numbers, 0.018gr. passed from the system in a short period. It was contained in the fæces, but how much is not stated. Taking in connection the quantity escaping with the liquid excrements, we may probably be justified in saying this amount passed away *daily.*

But we have seen that Jamaica water contains, after thirty-six hours' exposure, 0.00018gr. in a gallon, a quantity not one hundredth as large as that in the solid excrements above referred to.

It has already been suggested that the quantity so escaping might be considered as but one third of the whole ; — it would accordingly require a triple quantity to secure in this time the detention of two thirds in the organism. The period to which this view would bring the contemplation I will not venture to express. Neg-

been regarded with lead, namely, equal volumes of water to equal surfaces of substance, that comparison might be instituted.

Table XXV.

Experiments with Copper Turnings.

Water concentrated to one third of its volume.

Days.	Distilled Water.	Albany.	Cambridge.	Cochituate *a.*	Cochituate *b.*	Cochituate *c.*	Croton.	Fairmount.	Jamaica.	Troy.
1	——	——	——	——	——	——	——	——	——	——
11	0.001	0.500	0.000	0.001	0.002	0.000	0.000	0.000	0.001	0.000
17	1.000	0.500	1.000	0.500	1.000	1.000	0.010	0.500	0.010	0.500
25	0.005	0.001	0.002	0.050	0.080	——	0.002	0.001	0.050	0.001
37	0.000	0.000	——	0.005	0.050	0.050	——	0.000	——	0.010

These experiments show only a feeble action of aerated water on copper.

Table XXVI.

Experiments with Tin.

The tin contained arsenic as an impurity. Chemically pure tin yielded precisely the same results when exposed to the same waters. Bars of size already mentioned. 10cc. of water concentrated to from 3 to 5cc. Precipitates with hydrosulphuric acid and oxide of tin are both represented in the numbers below.

Days.	Cochituate.	Croton.	Fairmount.	Jamaica.	Distilled Water.	Albany.	Cambridge.	Troy.
1	——	——	——	——	——	——	——	——
2	0.100	0.100	0.000	0.000				
4	0.020	0.010	0.000	0.000	0.100			
6	0.010	0.010	0.000	0.000	0.000			
8	0.001	0.000	0.000	0.000	0.001			
10	0.005	0.000	0.000	0.000	0.000			
12	0.005	0.001	0.001	0.001	0.001	0.500	0.500	0.500
17	1.000	1.000	1.000	1.000	1.000	0.050	2.000	2.000
26	8.000	15.000	10.000	8.000	0.010	0.000	50.000	0.010
38	10.000	25.000	8.000	10.000	3.000	7.000	1.000	10.000
75	10.000	15.000	15.000	10.000	4.000	4.000	7.000	20.000

The action in ten days' exposure was inconsiderable. No coat formed on the tin.

lecting it, let it be supposed that in some cases the lead present in water will be doubled. The lease of life would still be for 6,840 years. If it were increased tenfold it would be reduced only to 684 years.

The foregoing note is in the main extracted from my last letter to the Water-Commissioners. See *Water-Com. Rep.*, 1848.

A portion of Cochituate water that had been standing two months in tin pipe, which was kindly furnished last February by the engineer of the water-works, was evaporated to dryness with carbonate of soda, and gave with the blowpipe a malleable metallic button. The *precipitated oxide* from this water, that from distilled water acting upon chemically pure tin, and that from Cochituate and the various other waters upon the impure tin, were identical in appearance.

Lehman remarks of the solubility of tin in solutions of salammoniac, alum, and bisulphate and bitartrate of potassa.*

'Lindes has examined the solutions which by boiling attack tin vessels. According to his experiments, tin is rapidly brought into solution, without precipitating the oxide by alum, salammoniac, and bisulphate of potassa. Without dissolving the oxide, but merely depositing it, chlorides of barium and calcium, neutral carbonate and bicarbonate of potassa, sulphates of potassa, soda, and magnesia, chloride of sodium, tartrates of ammonia and potassa, and borate of potassa.' †

These experiments were made with the aid of heat. Time accomplished the same end in all the waters I have employed, including distilled water, producing either solution or deposite of the oxide, *not* upon the tin, but the bottom of the containing vessel.

Lindes did not observe that saltpetre acted with the aid of elevated temperature. The time in his experiments was probably too short, as I have found that tin at common temperatures yields the insoluble oxide in a solution of saltpetre.

TABLE XXVII.

Experiments with Tinned Copper Pipe. ‡

Two days' exposure. 100cc. condensed to 5cc.

Days.	Distilled Water.	Cochituate.	Croton.	Jamaica.	Fairmount.	Albany.	Cambridge Hard Water.
2	15 000	20.000	10.000	20.000	20.000	20.000	20.000

Upon the authority of Dr. Hayes § I have ventured to speak of the safe use of tinned copper pipes, notwithstanding the fact of the slow erosion.

* *Taschenbuch der Chemie*, 1848, S. 192.

† Berzelius, *Jahrs Bericht*, Vol. XII., S. 110, 1833.

‡ The pipe, five eighths of an inch in diameter, was washed with warm diluted hydrochloric acid, then with warm diluted potassa, then with distilled water, and then successively exposed to the different waters mentioned above.

§ *Report to the Board of Consulting Physicians*, Boston, 1848.

Iron service-pipes such as are employed for the circulation of hot water and steam, for warming purposes, have been proposed, and are in use. I am informed that some persons who laid them down a few months since for the distribution of Cochituate water have decided to replace them with lead, on account of the rust, which unfits the water for washing.

Iron pipes *tinned* within and without have been submitted to me. I have no knowledge of the durability of the coat of tin. Should it prove to be lasting, this pipe will have the double advantage of the strength of iron and the feeble action which tin experiences.

A pipe consisting of *gutta percha* and *India rubber* was found to yield an extract to water, which gradually diminished, until the taste was no longer impaired. The strength of the specimen submitted to me was not sufficient to sustain the pressure of actual service.

Pipes of pure *gutta percha* have been proposed by Dr. Webster, and, from all the experiments I have been able to make, as well as from the known chemical properties of the substance, I shall not be surprised to find that they may be successfully introduced into wells. Its susceptibility to extension when heated, if only to the temperature of boiling water, precludes its use for some of the purposes of service-pipes.

Glass pipes have been used for the transmission of water, where the descent was moderate, and the head inconsiderable. Where the pressure is sufficient to supply the upper rooms of houses, practice has shown that the pipes are liable to be shattered by the concussion occasioned by shutting off the water.

Summary of Conclusions relating to the Different Kinds of Water and Leaden Service-pipe.

The waters used by man, in the various forms of beverage and for culinary purposes, are of two classes, viz.: —

1. *Open waters, derived from rain-falls and surface drainage, like ponds, lakes, rivers, and some springs; and*

2. *Waters concealed from sunlight, and supplied by lixiviation through soils or rock, or both, of greater or less depth, such as wells and certain springs.**

* Rain-water is to some extent employed as a beverage. It is more nearly allied to waters derived from surface drainage.

They differ, (*a.*) in temperature; well-water, through a large part of the year, is colder than lake, pond, or river water; — (*b.*) in the percentage of gases in solution; recently drawn well-water, in summer particularly, parts with a quantity of air upon exposure to the surface temperature. In winter these relationships must to some extent be inverted, in high latitudes for a longer, and in lower latitudes for a shorter period.

(*c.*) They differ in the percentage of inorganic matter in solution; well-waters contain more; — (*d.*) in the relative proportions of salts in solution; well-waters contain more nitrates and chlorides; — and (*e.*) in the percentage of organic matter; well-waters contain less.

Relations of Lead to Air and Water.

(*a.*) Lead is not oxidated in dry air, or (*b.*) in pure water deprived of air. (*c.*) It is oxidated in water, other things being equal, in general proportion to the amount of uncombined oxygen in solution. (*d.*) When present in sufficient quantity, nitrates in neutral waters are, to some extent, reduced by lead. (*e.*) Both nitrates and chlorides promote the solution of some coats formed on lead.

(*f.*) Organic matter influences the action of water upon lead. If insoluble, it impairs the action by facilitating the escape of air; if soluble, by consuming the oxygen in solution, and by reducing the nitrates when present. The green plants, so called, and animalculæ which evolve oxygen, are abundant in open waters in warm weather only, and of course when the capacity of water to retain air in solution is lowest; so that, although oxygen is produced in open waters by these microscopic organisms, it does not increase the vigor of their action upon lead.

(*g.*) Hydrated peroxide of iron (iron-rust) in water is not reduced by lead. Hence may be inferred the freedom from corrosion of leaden pipes connected with iron mains, so far as the reduction of the pulverulent peroxide of iron may influence it.

(*h.*) Alkaline chlorides in natural waters deprived of air do not corrode lead. (*i.*) Salts, generally, impair the action of waters upon lead, by lessening their solvent power for air, and by lessening their solvent power for other salts.

A coat of greater or less permeability forms in all natural waters to which lead is exposed. The first coat (*j.*) is a simple suboxide absolutely insoluble in water, and solutions of salts generally. This becomes converted in some waters into a higher oxide, and this higher

oxide, uniting with water and carbonic acid, forms a coat (*k.*) soluble in from 7,000 to 10,000 times its weight of pure water. The above oxide unites with sulphuric and other acids which sometimes enter into the constitution of the coat *k*; — uniting with organic matter and iron-rust, it forms another coat (*l.*) which is in the highest degree protective. The perfection of this coat, and of the first above mentioned, may be inferred from the small quantity of lead found in Croton water (New York), after an exposure in pipes of from twelve to thirty-six hours, and from the absence of an appreciable quantity in Fairmount water (Philadelphia), after an exposure of thirty-six hours, when concentrated to one two-hundredth of its bulk.

Reasons why the Water of Lake Cochituate served through Iron Mains and Leaden Distribution-pipes may be safely employed as a Beverage in any Form.

(*a.*) It has the small measures of air, nitrates, and chlorides, the large proportion of organic matter, soluble and insoluble, and exposure to the sun, above referred to as grounds of distinction in the relations to lead between lake, pond, or river water, and well-water.

(*b.*) In experiments with Croton, Fairmount, Jamaica, and Cochituate waters, made with lead, lead soldered to iron, to tin, to copper, and to brass, prolonged from mid-winter to the middle of summer, the relations of the last of these waters to lead were found to be as favorable as were those of either of the others.

(*c.*) Large numbers of individuals in the daily and unrestricted use of Fairmount, Croton, and Jamaica waters served through lead are not known by physicians of great eminence and extensive practice to suffer in any degree from lead maladies.

(*d.*) A coat forms upon lead in Cochituate, as in the other waters above mentioned, which for all practical purposes becomes, in process of time, impermeable to and insoluble in the water in which it occurs.